Search for 0.1 meV Axions and Hidden Photons Using Cu Resonant Cavities

P. L. Slocum, O. K. Baker, J. L. Hirshfield, Y. Jiang, G. Kazakevitch, S. Kazakov, M. A. LaPointe, A. Martin, S. Shchelkunov, A. Szymkowiak

Yale University

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Using a cylindrical Cu resonant cavity coupled to the pulsed 34.29 GHz magnicon at Yale, which provides several MW of RF power, we will search for the coupling (g $>10^{-6}$/GeV) of two photons to a light neutral boson in the presence of a strong axial magnetic field. Using the same apparatus, we will also look for mixing between photons and hidden sector photons ($\chi > 10^{-7}$). A second cylindrical Cu cavity will allow reconversion to a 34.29 GHz photon. This approach is analogous to the "light shining through a wall" technique that has been implemented at shorter wavelengths. We discuss the design of the experiment as well as the expected sensitivity of the apparatus.

1 Introduction

The search for new physics beyond the standard model of elementary particles has been fueled partly by the model's inability to address certain questions. For example it does not accommodate dark matter or dark energy, nor does it include a theoretical basis for the existence of gravity. It contains many parameters, such as the quark coupling constants, that have been measured empirically but whose magnitudes do not currently have theoretical explanations.

Extensions to the standard model have been proposed, several of which include a new light neutral boson (LNB) or axion–like particle (e.g., [1]). Other suggestions motivated by string theory [2, 3] predict a new "hidden sector" of particles that rarely interact with standard model particles. Of particular interest in these formulations is the region below 1 eV for hidden sector photons (HSPs) [3].

In this work we describe a "light shining through walls" experiment (see [4, 5, 6] and references contained therein) to search for LNBs and HSPs with masses near 34 GHz (0.1 meV). The experiment will be driven by the high–power 34 GHz microwave source at Yale ("magnicon") [7, 8], pulsed at 10 Hz with a 1 μs width and a peak power of several MW. Using two resonant cavities [3, 9] positioned inside a 7 T magnet, we will look for interactions between 34 GHz photons and the new particles.

2 Magnet and Cryostat

The superconducting magnet is a 7 T Oxford unit with a room temperature vertical bore of width 89 mm. The magnet was designed for NMR work and as such has a field that is uniform to

1 % within 1 cm of the coil's center. This uniformity is better than adequate for our experiment.

A separate cryostat has been custom built for this work by Cryo Industries, Inc. It consists of a He gas–cooled tube that fits vertically into the bore of the magnet. The coldest part of the tube will be placed into the center of the magnetic field and will be held at a temperature of approximately 10 K.

3 Resonant Cavities

There will be two resonant cavities made from OFHC copper in the experiment: a drive cavity and a signal cavity. The "drive" cavity will sit inside the bore of the magnet at the center of the field, but outside the separate cryostat. It will be critically coupled to the magnicon's power. The "signal" cavity will also be inside the bore, adjacent to the drive cavity, but will be inside the cooled tube of the cryostat.

The signal and drive cavity dimensions and positions have been chosen to optimize the product of the two–cavity geometry factor [3] for hidden sector photons

$$G(k/\omega_0) = \omega_0^2 \int_{V'} \int_V d^3\mathbf{x} d^3\mathbf{y} \frac{exp(ik|\mathbf{x}-\mathbf{y}|)}{4\pi|\mathbf{x}-\mathbf{y}|} A_{\omega_0}(\mathbf{y}) A'_{\omega_0}(\mathbf{x}),$$

squared, and the product of their two Qs. The result of the optimization is two side by side cylindrically shaped cavities, each operated in the TE011 mode. The Q of the drive cavity will be ~8000, and the Q of the signal cavity will be several times higher due to the cooling.

The drive cavity will be tuned thermally with chilled water. The signal cavity will be tuned mechanically. One end of the signal cavity consists of a movable plunger as shown in Figure 1. The plunger and cavity are sealed hermetically by a flexible bellows with a 4 mm range of motion.

The height of the tuning plunger is controlled by moving a central rod. The top end of the rod will be mounted to a stepper motor (Physik Instrumente C–863) that will control the height of the plunger with submicron resolution and stability.

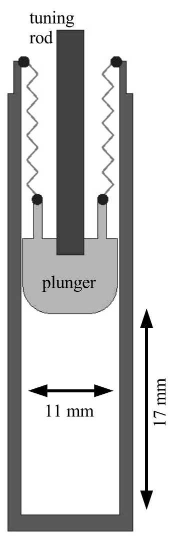

Figure 1: Sketch of the signal cavity with the plunger for tuning.

4 Receiver

The first component in the signal chain is a cryogenic amplifier with an integrated high electron mobility transistor (HEMT). The noise temperature of the HEMT amplifier at 34 GHz is approximately 22 K and its gain is 32 dB. Next the signal is mixed down to an intermediate frequency using a room–temperature Miteq AR2640LI8C.

After the mixer the signal is amplified by a series of room–temperature amplifiers preceded by a bandpass filter. The signal is filtered again before a diode detector. The DC output of the diode feeds into an Agilent 54855A oscilloscope for digitization before the PC–based data acquisition. Figure 2 shows a sketch of the initial components to be used in the receiver during the first phase of the experiment.

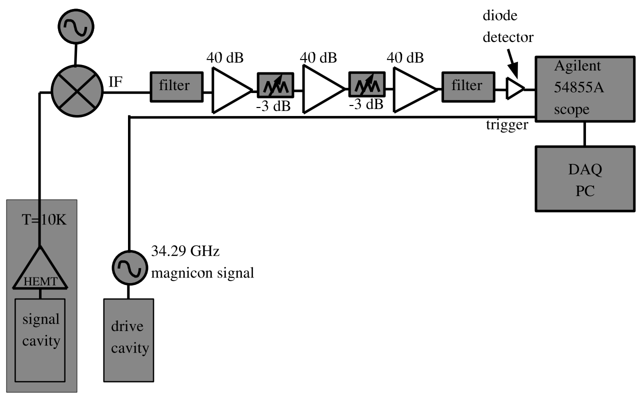

Figure 2: Subset of preliminary electronic components to be tested for use in the receiver.

5 Sensitivity

The sensitivity of the experiment to axion–like particles and hidden sector photons is defined in terms of a "5σ" measurement, where

$$\sigma = \frac{N_s}{\sqrt{N_b}} \equiv 5.$$

N_s is the total number of signal photons and N_b is the total number of background photons. In the case of axion–like particles, the probability of detection P_{det} is [10, 11, 3]

$$P_{det} \approx \frac{B_{ext}^2 l^2}{4M^2} QQ' |G_a|^2, \tag{1}$$

where B is the magnetic field, l is the pathlength of the photon in B, M is the mass of the axion, and G_a is the geometry factor of the experiment for axions.

The number of background photons N_b is determined assuming a flat thermal noise spectrum $k_B T_N B$, where B is the measurement bandwidth. The noise temperature T_N for the system is driven by the noise figure of the first cryogenic amplifier, and will likely be on the order of 50–100 K. This translates to a noise power of $\sim 10^{-15}$ W, which is reduced to 10^{-20} W by gating with the duty cycle of the magnicon.

The number of signal photons N_s for hidden sector photons, or paraphotons, is given by [3]

$$P_{trans} \approx \chi^4 QQ' \frac{m_{\gamma'}^8}{\omega_0^8} |G|^2, \tag{2}$$

where χ is the sensitivity for photon-paraphoton mixing [3], $m_{\gamma'}$ is the mass of the hidden photon, and ω_0 is the energy of the incident photon. Using Eqs. 1 and 2 and assuming a geometry factor of order unity, Figure 3 shows the expected sensitivity of the apparatus to LNB and HSP particles for several experimental configurations.

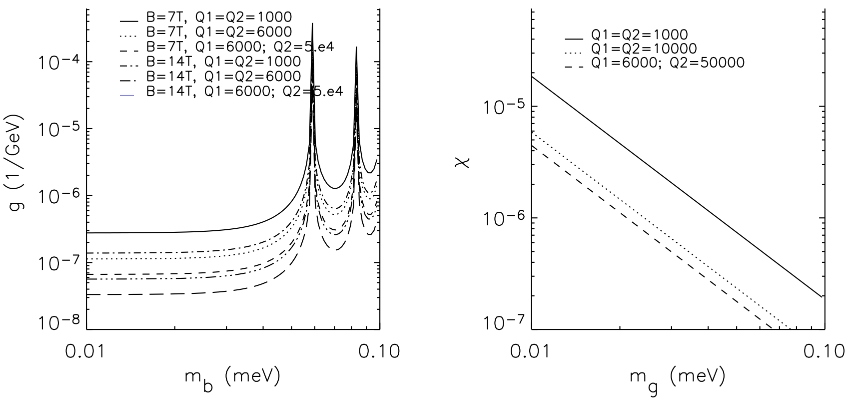

Figure 3: Plot of the expected results of this experiment for LNBs (left) and HSPs (right), assuming a range of values for the magnet field and cavity Qs.

6 Summary

The high power magnicon provides a unique opportunity to search for new particles with masses near 0.1 meV. The resonant cavity geometries have been optimized for efficiency and overall coverage. The initial receiver electronics have been selected to minimize noise power. With a cooled detector cavity and cryogenic amplifier, the sensitivity is expected to be on the order of g $> 10^{-6}$/GeV for LNBs and $\chi > 10^{-7}$ for HSPs.

7 Acknowledgments

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